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A Review on The Utilization of Construction 4.0 Technologies in Small-Scale Construction Supply Chain Management

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Abstract
Small-scale construction firms face persistent challenges in supply chain management due to limited digitalization and a continued reliance on traditional methods. These challenges lead to inefficiencies, resulting in significant waste and reduced productivity, and place small-scale firms at a disadvantage in a competitive market. This review explores the potential for utilizing Construction 4.0 technologies to enhance productivity and streamline supply chain management in small-scale construction. Through a comprehensive literature survey, a lack of awareness and adoption of digital tools was identified, revealing a key barrier to optimizing supply chain processes and achieving cost-effectiveness for these businesses. To gain further insight into current practices, a questionnaire survey will be conducted with engineers and suppliers involved in the small-scale construction supply chain, aiming to assess their specific needs and challenges. Insights from this survey will inform the design of a web-based application tailored to act as a digital tool for supply chain management, with a focus on improving productivity by addressing key factors impacting small-scale supply chains. This proposed tool will offer a user-friendly platform for streamlining supply chain operations, ultimately supporting small-scale firms in adapting to industry demands and enhancing their competitive positioning through digital transformation.

Keywords: *Construction 4.0, Digitalization, Supply Chain Management, Productivity Enhancement, Small-Scale Construction*

1. Introduction
The construction industry has long been characterized by its reliance on traditional methods, particularly in small-scale construction firms. These firms, which often operate with limited resources, face persistent challenges in supply chain management due to inefficiencies, waste generation, and a lack of productivity. Despite the transformative potential of digital technologies, such as those encompassed by Construction 4.0, small-scale construction businesses lag behind in digital adoption. This digital divide exacerbates their challenges, leaving them at a competitive disadvantage in an increasingly dynamic and demanding market. Construction 4.0 refers to the integration of advanced technologies, such as the Internet of Things (IoT), Building Information Modeling (BIM), cloud computing, and automation, to revolutionize traditional construction processes. These innovations promise significant benefits, including enhanced supply chain visibility, reduced material waste, improved project timelines, and cost optimization. However, small-scale construction firms often struggle with adopting these technologies due to barriers such as high implementation costs, lack of awareness, and insufficient technical expertise. This review aims to bridge the knowledge gap by exploring the applicability of Construction 4.0 technologies to the supply chain management of small-scale construction firms. Through a comprehensive literature survey, key barriers to the adoption of digital tools have been identified, highlighting the need for tailored solutions to meet the unique needs of these firms. To further investigate current practices, a questionnaire survey will be

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conducted targeting engineers and suppliers within the small-scale construction supply chain. The findings will guide the development of a user-friendly web-based application designed to address specific challenges and streamline supply chain operations. By leveraging digital transformation through Construction 4.0 technologies, this study seeks to empower small-scale construction firms to overcome operational inefficiencies, reduce costs, and enhance their competitive positioning. This review sets the foundation for a practical, scalable solution that aligns with the evolving demands of the construction industry [1-3].

1.1. SCM: The Role in Construction

Supply Chain Management (SCM), initially developed for the manufacturing industry, plays a critical role in managing business processes systematically to enhance quality, reduce time, and boost profitability (Wisner et al., 2011).

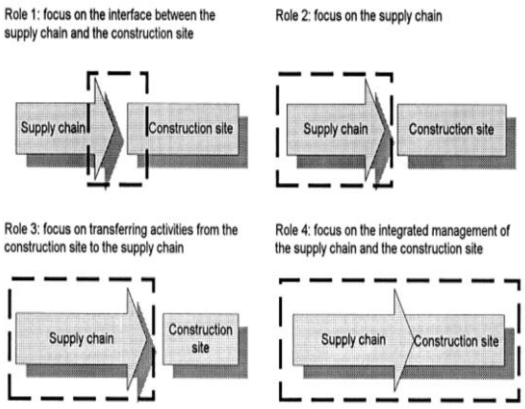

Figure 1 Supply chain management role in construction (Vrijhoef and Kosksela, 2000)

In contrast, the adoption of SCM practices within the construction sector remains fragmented and limited. Akintoye et al. (2000) highlighted in their study that the interactions between clients, suppliers, and contractors are predominantly centered around procurement and production planning. This indicates that SCM has only been partially integrated into the construction industry in the UK. Additionally, Vrijhoef and Koskela (2000) emphasized the significance of SCM in construction, identifying four primary roles it serves. These roles are determined by the focus of industry challenges, whether related to the broader supply chain, the construction site, or both, as illustrated in Figure 1 [4-7].

1.2. Construction Supply Chain Characteristics

Construction supply chains (CSC) in small-scale projects are inherently complex, despite their relatively smaller scope compared to large-scale endeavors. This complexity is driven by the diverse range of materials and the numerous stakeholders, including suppliers and subcontractors, that must collaborate to complete the project. As small-scale projects often rely on a mix of first-tier, second-tier, and other subcontractor tiers, the supply chain becomes intricate, requiring significant coordination. While smaller projects may involve fewer resources than large ones, the challenges of planning, organizing, and fostering collaboration among stakeholders remain equally significant. The relationship between project scope and supply chain complexity is also evident in small-scale construction. As the scope grows, even modestly, more materials, manpower, and parties become necessary, adding to the coordination burden. For example, small construction firms often interact with multiple suppliers and subcontractors annually, necessitating efficient supply chain management to minimize delays and costs. However, limited resources and reliance on traditional practices often impede the adoption of streamlined processes, intensifying challenges for small firms. Vrijhoef (1998) studied construction supply chains in residential building projects and identified several key characteristics that also apply to small-scale CSCs:

- **Converging Supply Chain:** Small-scale construction supply chains are converging in nature, meaning all materials, documentation, and resources must be delivered to the site by suppliers and subcontractors under the main contractor's supervision. This creates a centralized flow of resources to serve a single or limited group of end users.
- **Make-to-Order Supply Chain:** Like large projects, small-scale construction is client-driven, with the end user initiating the project. This often leads to the client being directly involved in key decisions throughout the construction process.

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- **Fragmented Supply Chain:** The fragmentation in small-scale projects is pronounced due to the involvement of multiple, often temporary, participants. Contractors, suppliers, and other stakeholders operate at different stages of the project, frequently resulting in unclear authority and divided responsibilities.
- **Temporary Supply Chain:** Small-scale construction supply chains are highly transient. Once a project concludes, the teams and suppliers involved are usually dismissed. This short-term nature can lead to inefficiencies, such as inconsistent performance or gaps in knowledge transfer across projects.

Muya et al. (1999) identified additional features that are particularly relevant to small-scale construction supply chains [8-10]:

- **Primary Supply Chain:** Delivers core materials and components such as raw materials, sub-assemblies, and basic equipment required for project completion.
- **Support Chain:** Provides essential resources, such as tools and minor equipment, that simplify construction processes. Small firms often rely heavily on these chains due to limited in-house resources.
- **Human Resource Supply Chain:** Ensures the availability of skilled labor and supervisory staff, which is crucial for maintaining efficiency in smaller projects where teams are lean.

In small-scale construction, these supply chain elements face unique challenges. Limited digitalization and dependence on traditional methods exacerbate inefficiencies, including material wastage and coordination delays. Additionally, the temporary and fragmented nature of small-scale supply chains makes collaboration and communication between stakeholders particularly challenging.

1.3. Small-Scale Construction Supply Chains and Construction Industry Problems

The construction industry, particularly in the context of small-scale construction supply chain (CSC) management, faces numerous challenges that significantly hinder its efficiency and growth. Yeo and Ning (2002) identified several persistent problems, including budget overruns, project delays, low profit margins, and frequent legal disputes. Vrijhoef and Koskela (2000) further attributed these issues to the narrow and short-term focus often applied to the control of construction supply chains, which exacerbates inefficiencies and waste. These issues are often more pronounced in small-scale construction due to limited resources and fragmented supply chain practices. From a demand-supply perspective, Cox, Ireland, and Townsend (2006) categorized construction industry challenges into demand-related issues, supply-related issues, and common challenges. These problems are equally relevant and often more impactful in the small-scale sector due to its constrained operations and reliance on traditional methods:

1.3.1. Demand-Related Issues in Small-Scale CSCs

- **Inappropriate Selection Criteria:** Small-scale projects often award contracts based solely on the lowest price, ignoring the overall value offered by contractors. This practice can result in substandard quality, reduced trust, resistance to necessary design changes, and additional claims for unforeseen costs.
- **Discontinuous and Low Demand:** Economic downturns or unstable markets disproportionately impact small-scale construction firms, leading to sporadic demand for services and financial instability. This limits their ability to sustain long-term operations or invest in process improvements.
- **Inappropriate Allocation of Risk:** Risk distribution in small-scale projects is often skewed, with clients shifting disproportionate responsibilities onto contractors. This creates financial and operational strains on small firms.
- **Frequent Changes in Specification:** Clients frequently altering project specifications mid-construction pose significant challenges to small-scale firms, often leading to cost overruns and delays due to limited flexibility and resources.

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1.3.2. Supply-Related Issues in Small-Scale CSCs

- **Poor Public Image:** Small-scale firms struggle to attract skilled professionals due to perceptions of low job security, limited career advancement, and poor working conditions within the construction industry.
- **Inefficient Construction Methods:** Small firms often face difficulties integrating design and construction processes effectively, leading to inefficiencies and reduced buildability. This is especially common in sectors like residential housing, where outdated practices persist.
- **Poor Quality:** A lack of stringent entry regulations allows inexperienced firms to compete in the small-scale construction market, undermining quality and tarnishing the reputation of the sector as a whole.

1.3.3. Common Issues in Small-Scale CSCs

- **Fragmented Industry Structure:** The reliance on multiple layers of subcontractors, many of whom lack proper training or experience, leads to fragmentation. Small-scale projects often suffer from poorly coordinated workflows and unmet specifications due to unqualified subcontractors being involved.
- **Adversarial Culture:** Adversarial relationships between clients, contractors, and subcontractors are common in small-scale construction. These tensions hinder collaboration, reduce trust, and impede the adoption of modern procurement practices.
- **Inadequate Investment in Training:** Limited budgets in small-scale firms often mean minimal investment in staff training or research and development. This leads to stagnation and a lack of innovation, further reducing competitiveness.
- **Poor Management:** Ineffective project and site management are critical issues in small-scale construction. With fewer resources and less oversight, small firms frequently experience delays, cost overruns, and reduced productivity.

1.4. Supply Chain Management Benefits in Small-Scale Construction Supply Chain

Modern approaches to procurement in small-scale construction are increasingly emphasizing integrated supply chains. This approach promotes collaboration and alignment of objectives among all participants in the supply chain, resulting in greater goal congruence and added value for the client. Traditionally, the relationship between small-scale contractors and clients was defined by rigid contracts with predetermined prices and specifications. In this conventional model, clients had limited involvement, contractors often lacked motivation to prioritize client interests, and coordination between contractors and designers was minimal, typically managed through separate agreements. In contrast, adopting integrated supply chain methods within small-scale construction allows Supply Chain Management (SCM) to be more effectively implemented, overcoming the limitations of traditional practices. The benefits of integrated supply chains for small-scale construction firms include:

- **Cost and Waste Reduction:** Streamlined processes reduce material waste and operational inefficiencies, which are critical for small-scale firms operating on tighter budgets.
- **Risk Mitigation:** Improved collaboration and transparency provide greater certainty in project costs, reducing financial and operational risks for smaller projects.
- **Value for Clients:** Integrated approaches ensure better communication and alignment, delivering higher-quality outcomes and improving client satisfaction.
- **Facilitation of Long-Term Planning:** Collaborative relationships enable small firms to engage in more effective project scheduling and resource allocation.
- **Opportunities for Repeat Business:** Satisfied clients are more likely to return for future projects, fostering stability and growth for small-scale firms.

By adopting an integrated supply chain model, small-scale construction firms can improve their service delivery. Clients and end users benefit from timely

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project completion, reduced costs, and minimized defects, which enhances confidence in the construction process and the industry as a whole. Additionally, Erikson (2010) noted that integrated supply chains offer small construction firms better control over their operations, further aiding in cost reduction and process efficiency [11-14].

1.5. The Need of Information Sharing in Construction Supply Chains

In small-scale construction projects, the supply chain can be viewed as comprising two distinct processes: the supply process and the construction process (Friblick 2000; Thunberg 2016). These processes operate on different principles. The construction process, typically following an engineer-to-order (ETO) logic, focuses on designing and executing the project. It involves key actors such as the project developer, who initiates the project, and the main contractor, who organizes and executes it. Small-scale construction projects often involve multiple subcontractors, reflecting the fragmented nature of the industry (Dubois and Gadde 2002; Miller, Packham, and Thomas 2002). Conversely, the supply process often operates under varying production logics, such as make-to-order (MTO), assemble-to-order (ATO), or make-to-stock (MTS) (Hicks, McGovern, and Earl 2000). This diversity adds complexity to small-scale projects, where main contractors must carefully manage lead times and ensure that materials are delivered on schedule to avoid delays. For example, MTO and ATO suppliers typically require more detailed planning due to their longer lead times, whereas MTS suppliers, with inventory readily available, often result in less transport efficiency due to frequent small deliveries (Ying, Tookey, and Seadon 2018). In small-scale construction, coordination between the supply chain actors and the construction site remains challenging. Main contractors are responsible for integrating these processes, yet planning efforts are often skewed towards on-site production rather than supply chain optimization (Ko, Azambuja, and Felix Lee 2016). The fragmented and temporary nature of small-scale construction exacerbates these issues, making effective collaboration and information sharing among stakeholders more difficult (Modig 2007; Dainty, Moore, and Murray 2006). Key obstacles to efficient small-scale supply chain management include:

- **Limited Information Sharing:** Information on project progress, inventory levels, and delivery schedules is often not effectively communicated between contractors and suppliers, leading to misaligned operations and inefficiencies (Fellows 2009; Shin et al. 2011).
- **Temporary Relationships:** Short-term partnerships in small-scale projects hinder the development of trust and collaboration, making it difficult to build long-term efficiencies (Meng 2012).
- **Manual Processes:** Due to the low level of digitalization in small-scale construction, much of the information flow relies on manual collection and communication, increasing the likelihood of errors and delays (Ko, Azambuja, and Felix Lee 2016).
- **Fragmented Purchasing Practices:** Strategic purchasing decisions are often separated from on-site operational purchasing, leading to inconsistencies in material availability and delayed deliveries (Thunberg and Fredriksson 2018).

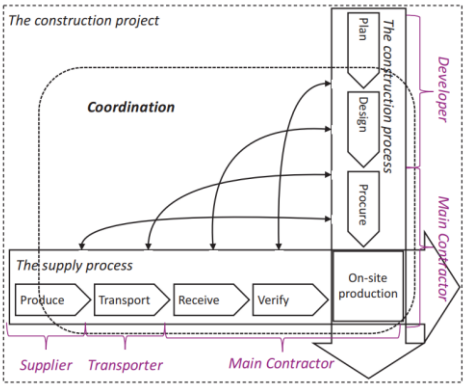

Figure 2 Relationship Between a Construction project, and its Construction Process and Supply Process, Adapted from Friblick (2000) and Thunberg (2016)

The unique challenges of small-scale construction demand a more integrated approach to supply chain management. Main contractors must foster better coordination with suppliers, including sharing real-

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time information on project progress, inventory levels, and logistical needs. Effective use of digital tools can mitigate many of these challenges by streamlining communication and enhancing supply chain visibility. Despite these challenges, small-scale construction offers significant opportunities to improve supply chain performance through better collaboration and integration. As Akintoye (1995) highlighted, understanding suppliers' needs and tailoring delivery schedules based on the specific demands of the project are critical to minimizing disruptions and ensuring efficient project execution. Future research should focus on exploring innovative solutions for information sharing and digital adoption tailored specifically to the needs of small-scale construction supply chains, shown in Figure 2.

1.6. Industry 4.0 in the Construction Industry

Industry 4.0 represents the fourth industrial revolution, encompassing digitization and automation across various sectors, including manufacturing and construction. Although primarily applied in manufacturing, Industry 4.0 is steadily transforming the construction industry, presenting both opportunities and challenges, particularly in small-scale construction supply chain management (SCM). Small-scale construction projects face unique obstacles, such as highly fragmented supply chains involving multiple small and medium-sized enterprises (SMEs), resource constraints, and project-specific complexities. These factors often result in inefficiencies, delays, and limited adoption of advanced technologies. However, the integration of Industry 4.0 concepts offers solutions to address these challenges effectively. Building Information Modeling (BIM) is one of the central technologies driving digital transformation in construction. For small-scale projects, BIM facilitates better visualization, collaboration, and resource optimization. By leveraging cloud-based platforms, contractors and suppliers can coordinate more effectively, reducing delays and preventing rework. Automation and robotics also play a crucial role in improving productivity and reducing labor costs. Technologies such as robotic bricklayers and 3D concrete printers, while often associated with large-scale projects, can be adapted for smaller projects to enhance efficiency and lower costs. The Internet of Things (IoT) and RFID technology offer affordable solutions for real-time tracking of materials and equipment. These technologies enhance transparency, minimize delays, and streamline inventory management. Similarly, cloud computing and mobile applications provide practical tools for project tracking, communication, and data sharing among stakeholders, ensuring smoother coordination and decision-making. Augmented Reality (AR) and Virtual Reality (VR) further enhance project planning and client engagement. AR can assist in on-site inspections and quality control, while VR allows clients to visualize designs early, reducing the likelihood of changes during construction. Wearable technologies such as smart helmets and glasses also improve safety and communication on-site, making them valuable even for small projects. The benefits of adopting Industry 4.0 technologies in small-scale construction SCM are significant. Cost savings can be achieved through automation, prefabrication, and better inventory management. Improved coordination between contractors and suppliers reduces waste and delays, while digital tools enable more accurate scheduling and resource allocation. Additionally, these technologies enhance safety and client satisfaction, ultimately fostering more efficient and reliable construction processes. Despite these advantages, implementing Industry 4.0 in small-scale construction requires careful planning and phased adoption. SMEs can start with accessible tools such as mobile apps or cloud-based platforms before exploring advanced technologies like robotics or big data analytics. Collaboration among contractors and suppliers can also help share costs and resources, making these innovations more feasible. In summary, while small-scale construction projects face distinct challenges, Industry 4.0 offers transformative potential to streamline supply chain management, improve productivity, and enhance overall project outcomes. By adopting scalable and cost-effective solutions, small-scale construction firms can effectively embrace digital transformation and address the inefficiencies inherent in their operations.

2. Literature Review

The construction industry, segmented into large companies managing multimillion-dollar projects and small to medium-sized enterprises (SMEs), often

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family-run and owner-directed, presents unique challenges in implementing effective supply chain management (SCM). Construction supply chains (CSCs) are inherently fragmented and complex, comprising the primary supply chain, the support chain, and the human resource supply chain. Collaboration among key stakeholders—clients, contractors, suppliers, and subcontractors—is essential for efficiency, requiring long-term partnerships, transparent communication, and mutual sharing of risks and benefits. Early involvement of subcontractors and suppliers is also critical to align processes, minimize risks, and foster project success. Despite these strategies, SCM implementation in construction faces significant barriers. Ineffective leadership, lack of competence in SCM principles, passive subcontractor participation, and organizational resistance remain critical obstacles. Additionally, limited awareness of the importance of coordination among stakeholders and insufficient IT adoption further hinder progress. Studies have identified seven key challenges: fragmented industry characteristics, limited SCM capabilities, poor collaborative support systems, inadequate experience with innovations, and insufficient understanding of advanced IT frameworks. These challenges necessitate a shift towards more integrated and technology-driven approaches. Technological advancements associated with Industry 4.0, such as digitalization, Building Information Modeling (BIM), cloud computing, and the Internet of Things (IoT), are gradually reshaping CSCs. These technologies enable enhanced coordination, real-time tracking, and better resource management. Companies integrating technologies like RFID, GIS, and 3D printing have demonstrated improvements in supply chain efficiency, particularly in areas such as progress monitoring and resource optimization. BIM is increasingly recognized as a central tool for improving collaboration, early problem detection, and reducing waste. Blockchain-smart contracts and IoT applications are also emerging as vital tools for automating processes and enhancing transparency, although cybersecurity concerns and limited integration with sustainability initiatives remain challenges. Lean construction principles further complement SCM by emphasizing waste reduction, continuous improvement, and customer focus. The integration of lean principles with supply chain collaboration has shown potential to enhance project efficiency and reduce costs. Technologies like BIM facilitate the implementation of lean practices by improving planning accuracy and stakeholder communication. Early contractor involvement and joint market research have also been identified as critical enablers of lean SCM integration. Research underscores the importance of factors such as effective communication, stakeholder management, clear objectives, and senior management support in ensuring the success of SCM initiatives. Tools like the Analytical Hierarchy Process (AHP) are used to evaluate supplier performance against criteria including financial stability, technical capability, quality competence, and delivery reliability, ensuring balanced and informed supplier selection. However, SCM adoption remains limited due to resistance to change, lack of knowledge about its benefits, and weak policy support. Opportunities for further research include exploring the integration of BIM with blockchain and IoT, addressing cybersecurity concerns, and aligning digital supply chain platforms with sustainability goals. The growing intersection of Industry 4.0, lean principles, and SCM offers significant potential for improving flexibility, agility, and collaboration within the construction supply chain. Addressing these areas can bridge existing gaps and drive the transformation of CSCs toward more efficient, technology-driven systems [15-17].

3. Research Methodology

To achieve the objectives of this study, a survey questionnaire was designed to gather insights from small-scale suppliers and engineers in the construction industry. The development of the questionnaire was grounded in an extensive literature review that identified critical challenges, opportunities, and factors influencing construction supply chain management (CSCM). Based on these findings, the initial questionnaire was structured to explore existing processes, stakeholder ideologies, expectations for digital tools, and key factors affecting productivity. A pilot study was conducted to validate the questionnaire, involving feedback from a select group of respondents. The participants were asked to evaluate the clarity, relevance, and

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comprehensiveness of the questions. Minor revisions were made to improve readability and precision, but the overall structure and themes remained consistent, as the preliminary questions effectively addressed the study's objectives. This iterative refinement ensured the questionnaire's reliability and relevance to the target audience. The finalized questionnaire comprised open-ended qualitative questions, divided into three sections. The first section provided participants with an overview of the study's purpose and the fundamental concepts of CSCM. The second section invited respondents to share their experiences and opinions regarding the current supply chain processes, their expectations for digitalization, and their views on productivity improvement. This section was pivotal in capturing diverse and in-depth perspectives. The final section collected demographic data, including the respondents' roles, years of experience, and organizational type, to contextualize their responses. The data collection involved administering the questionnaire to 25 small-scale suppliers and 25 small-scale engineers. Their responses provided valuable insights into the challenges and potential solutions for improving CSCM through digital tools. The qualitative nature of the survey allowed for the identification of recurring themes and unique suggestions, which were systematically reviewed and analyzed to propose recommendations. These findings will contribute to the development of a framework aimed at integrating Construction 4.0 technologies into small-scale CSCM processes [18-22].

4. Questionnaire Design

The questionnaire design for this study was framed to comprehensively explore the current state of supply chain management (SCM) in small-scale construction projects, focusing on the perspectives of engineers and suppliers. The ultimate aim was to identify challenges, expectations, and potential improvements, particularly in the context of integrating Construction 4.0 technologies to enhance the efficiency and effectiveness of SCM [23-25].

4.1. Rationale Behind Questionnaire Design

The questionnaire was structured to capture both qualitative insights and specific data about the current supply chain processes, challenges, and potential areas for improvement. The questions were designed to address two distinct yet complementary perspectives: the engineers responsible for managing construction materials and the suppliers tasked with delivering them. By gathering input from both sides, the questionnaire aimed to provide a holistic view of the supply chain dynamics.

4.2. For Engineers

The questions directed at engineers were intended to understand the practicalities of material management, inventory tracking, and the challenges they face in ensuring timely delivery. Engineers, being directly involved in the planning and execution of construction projects, provided valuable insights into the logistical and operational aspects of the supply chain.

4.3. Process Understanding

"What are the typical steps you follow in managing construction materials from planning to delivery?"
This question aimed to understand the workflow engineers follow and identify potential bottlenecks or inefficiencies in their material management processes.

4.4. Inventory Tracking

"How do you track your material inventory?"
This question sought to assess the methods or tools used by engineers to monitor stock levels and the effectiveness of their inventory management practices.

4.5. Delivery Challenges

"What challenges do you face in ensuring timely delivery of materials?"
The goal was to identify common obstacles in the material delivery process and gauge the impact these challenges have on project timelines.

4.6. Technology Usage

"What types of technology or tools do you currently use for managing the supply chain?"
This question aimed to uncover the technologies engineers are currently utilizing and assess their effectiveness in streamlining the supply chain.

4.7. Handling Delays

"How do you handle delays or unexpected changes in material requirements?"By understanding how engineers manage unforeseen disruptions, the study could highlight areas where digital tools might improve flexibility and responsiveness in the supply chain.

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4.8. Potential Improvements

"Are there any areas where you feel improvements could be made in the current supply chain process?"
This open-ended question allowed engineers to offer suggestions for improvement, which could guide the development of more efficient systems or tools.

4.9. For Suppliers

The questions directed at suppliers aimed to understand the supply-side challenges, their methods of inventory management, order fulfillment, and communication practices with construction teams. Suppliers are key stakeholders in ensuring that materials are delivered on time and in the right quantities, so their feedback was crucial for the study.

4.10. Order Process

"Can you walk me through the process of receiving an order request from an engineer or construction company?"
This question was designed to understand the suppliers' workflow and any pain points they encounter when receiving and processing orders from construction teams.

4.11. Inventory Management

"How do you manage inventory to ensure materials are available for delivery when needed?"
This question aimed to assess the strategies suppliers employ to ensure that stock levels meet demand and how they handle fluctuations in material needs.

4.12. Order Fulfillment Challenges

"What are the common challenges you encounter in fulfilling orders on time?"
Identifying these challenges provided insight into the factors that hinder timely delivery and how digital solutions might help overcome them.

4.13. Digital Tools for Order Management

"Do you use any digital tools to track and manage orders? If so, which ones?"
This question explored the current use of digital tools among suppliers, providing insight into existing technologies and their effectiveness in managing the supply chain.

4.14. Communication with Construction Teams

"How is communication maintained between you and the construction team during the supply process?"
Effective communication is a key factor in supply chain efficiency. This question sought to assess the communication methods used and any challenges in maintaining smooth interactions.

4.15. Suggestions for Improvement

"In your opinion, what improvements could be made to streamline the supply chain process from your perspective?" This open-ended question allowed suppliers to provide their recommendations on improving the supply chain, which could directly inform the development of a digital tool.

4.16. Designing the Digital Tool

To gain direct input on the development of a digital tool to manage the supply chain process, a set of additional questions was included:
"I am developing a digital tool to manage the supply chain process. What are your suggestions for essential features to include, elements to avoid, and the best structure for the tool's design?"
This question allowed respondents to directly contribute their ideas for the features and design elements that should be prioritized in a digital tool, ensuring the tool is user-friendly and meets the practical needs of both engineers and suppliers.

4.17. Factors Impacting Productivity

"In your experience, what key factors do you consider to most significantly impact productivity in the management of supply chains within small-scale construction projects?"
By identifying these key factors, this question aimed to understand the main productivity challenges faced in small-scale construction supply chains and identify opportunities for improvement through digital solutions.

4.18. Questionnaire Structure

The questions were structured to facilitate an easy flow of information while ensuring that critical aspects of the supply chain process were covered. Open-ended questions were used to allow for detailed responses and to capture insights that may not have been anticipated. By combining both qualitative and quantitative questions, the questionnaire was designed to gather in-depth feedback that could inform the development of a digital tool aimed at improving supply chain management in small-scale construction projects. The combination of these questions and their design was intended to capture the challenges, expectations, and suggestions of both engineers and suppliers, thereby enabling a comprehensive understanding of the issues at hand

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and providing the necessary data for developing an effective solution.

5. Data Analysis

5.1. Traditional Supply chain Process

The traditional supply chain process in small-scale construction projects is informal and fragmented, relying heavily on manual processes and direct communication between suppliers and engineers. For suppliers, the process begins with receiving an order request specifying materials, quantities, and delivery requirements, followed by checking inventory availability. If materials are unavailable, they must be sourced from external vendors, often leading to delays due to lead times and negotiations. Once materials are ready, suppliers handle packaging, labeling, and scheduling deliveries, maintaining communication with engineers to ensure timely arrivals. Invoices are issued post-delivery, with payments processed as per agreed terms. Engineers, on the other hand, start by identifying required materials based on project specifications, placing orders with clear delivery instructions, and monitoring progress to ensure materials arrive on time. Upon delivery, they inspect and store materials appropriately for use. However, this process faces significant challenges, including delays from inventory shortages, logistical constraints, and communication breakdowns, exacerbated by manual inventory management and unforeseen changes in material requirements. These inefficiencies in the traditional process lead to delays, material shortages, and operational disruptions, underscoring the need for more streamlined and flexible approaches.

5.2. Tracking of Stock and Inventory

Tracking stock and inventory in small-scale construction supply chains is predominantly a manual and labor-intensive process, relying on basic systems like spreadsheets or physical ledgers, which are prone to errors such as incorrect data entry, missing records, and delays in updates. Suppliers monitor stock levels by recording material inflows and outflows and often conduct periodic physical counts to verify inventory, which is time-consuming and disruptive. Discrepancies in inventory can lead to shortages, requiring suppliers to reorder materials from external vendors, causing delays, especially when materials have long lead times or sourcing issues. Engineers face even greater challenges due to a lack of real-time updates and inconsistent communication with suppliers, often resulting in delays, rushed procurement, or material substitutions that may compromise quality. The absence of dedicated software tools or automated systems exacerbates these inefficiencies, leaving inventory tracking dependent on phone calls, emails, or face-to-face communication, which further delays information flow and increases errors. These limitations lead to frequent issues such as stockouts, excess inventory, and delays in material delivery, highlighting the need for advanced tools and technologies to automate inventory management, enhance communication, and provide real-time updates for better decision-making and planning [26-28].

5.3. Challenges During Timely Delivery

Timely delivery of materials is a critical yet challenging aspect of small-scale construction supply chains, impacted by logistical issues, communication gaps, and resource limitations. Suppliers face obstacles such as traffic congestion, vehicle breakdowns, and reliance on third-party transport providers, compounded by sudden demand surges, inaccurate order forecasting, and delays in replenishing stock. Coordination issues with the construction team often result in miscommunication about delivery timelines. For engineers, late deliveries disrupt project schedules, causing delays, rescheduling, idle time for labor and equipment, and increased costs. The lack of real-time tracking and communication further exacerbates these problems, as engineers depend on inconsistent verbal or written updates, which can lead to unanticipated arrivals or delays that halt critical activities. Limited supplier resources, such as small fleets or personnel, make it difficult to prioritize deliveries when multiple projects compete for materials. The absence of integrated digital platforms for tracking, route optimization, and communication forces both suppliers and engineers to rely on reactive, traditional methods that fail to prevent delays. These challenges underscore the need for improved logistics management, enhanced communication, and the adoption of digital tools to ensure efficient coordination, minimize disruptions, and maintain project timelines.

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5.4. Knowledge on Tools and Technologies

Knowledge of tools and technologies among stakeholders in small-scale construction supply chains is often limited, leading to inefficiencies and missed opportunities for process optimization. Many suppliers and engineers rely on traditional, manual methods for managing the supply chain, such as spreadsheets, handwritten records, and direct communication, due to a lack of awareness or access to advanced digital tools. While some individuals are familiar with basic software like inventory trackers or accounting systems, the use of more sophisticated technologies—such as enterprise resource planning (ERP) systems, real-time tracking platforms, or Construction 4.0 tools like IoT sensors and AI-driven analytics—is minimal. Suppliers often view these technologies as costly or complex to implement, while engineers may lack the training or resources to adopt them effectively. The disconnect between the available technology and its practical implementation is further compounded by limited collaboration between suppliers and engineers to explore or adopt such innovations collectively. This lack of technological adoption restricts stakeholders from benefiting from real-time data, streamlined communication, and automated processes, ultimately resulting in delays, increased costs, and reduced productivity. The gap in knowledge and utilization of tools and technologies highlights the need for targeted education, training programs, and affordable solutions tailored to the specific needs of small-scale construction projects.

5.5. Communication During Supply Process

Communication during the supply process in small-scale construction projects is often informal and inconsistent, creating significant challenges for both suppliers and engineers. Most communication occurs through phone calls, emails, or face-to-face interactions, which are prone to delays, misunderstandings, and incomplete information sharing. Suppliers frequently face difficulties in conveying accurate updates regarding material availability, delivery schedules, or potential delays, leading to uncertainty on the part of engineers. On the other hand, engineers struggle to maintain clear and continuous communication with suppliers, especially when project timelines change or material requirements are adjusted. The lack of standardized communication protocols or platforms exacerbates these issues, as crucial details are often lost or misinterpreted. Additionally, small-scale supply chains rarely use digital tools or centralized systems to streamline communication, relying instead on fragmented and manual approaches. This results in delays, poor coordination, and missed opportunities to resolve issues proactively. The communication gaps not only affect the timely delivery of materials but also create inefficiencies in planning and execution, ultimately impacting project timelines and costs. Addressing these challenges requires implementing more structured and technology-driven communication strategies to improve transparency, responsiveness, and collaboration throughout the supply process.

5.6. Unexpected Changes in Material requirements

Unexpected changes in material requirements pose a significant challenge in small-scale construction supply chains, often disrupting both planning and execution. These changes can arise from design modifications, unforeseen site conditions, or adjustments to project timelines, leaving suppliers and engineers scrambling to adapt. For suppliers, such changes frequently result in rushed procurement, the need to source additional materials on short notice, and increased pressure on inventory management. This situation is further complicated by limited stock availability or long lead times for specific materials, leading to potential delays in fulfilling the revised requirements. Engineers, on the other hand, face the challenge of reassessing project schedules and reallocating resources to accommodate the new demands, which can cause delays in ongoing tasks and impact overall productivity. Communication gaps between engineers and suppliers often exacerbate these issues, as updates regarding changes in material needs may not be conveyed promptly or accurately. The reliance on manual processes and the absence of real-time inventory tracking tools leave both parties ill-equipped to respond swiftly to such changes, resulting in inefficiencies and increased costs. Addressing these challenges requires enhanced collaboration, proactive planning, and the integration

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of digital tools to enable dynamic adjustments and improve responsiveness to evolving project requirements.

5.7. Areas of improvement

Identifying areas that need improvement in small-scale construction supply chains is essential to address the inefficiencies and challenges faced by suppliers and engineers. One critical area is the integration of digital tools and technologies, as many small-scale operations still rely on manual processes for inventory management, tracking, and communication. This lack of automation leads to delays, errors, and inefficiencies that could be mitigated with real-time systems. Another area is communication, where inconsistent and delayed information exchange between suppliers and engineers often results in misaligned expectations, delivery issues, and project disruptions. Improving logistics management is also a priority, as many suppliers struggle with limited transportation resources and ineffective route planning, causing delays in material delivery. Additionally, there is a need for better forecasting and demand planning to ensure material availability without overstocking or stockouts. Training and knowledge enhancement for both suppliers and engineers on emerging tools, technologies, and supply chain best practices can also contribute to significant improvements. Establishing stronger collaboration and feedback mechanisms, supported by digital platforms, could further streamline processes, reduce errors, and enhance overall supply chain performance.

5.8. Expectation on Construction 4.0 Implementation

Suppliers and engineers expressed a strong interest in implementing Construction 4.0 technologies to streamline small-scale construction supply chains, with clear expectations for the design and functionality of digital tools. Both groups emphasized the need for a user-friendly interface that allows seamless navigation and quick access to essential features, as many users may not have advanced technical expertise. Real-time tracking of inventory levels, automated alerts for low stock, and live updates on delivery status were highlighted as critical requirements to enhance transparency and minimize delays. Engineers suggested incorporating features for advanced demand forecasting and project-specific material planning, while suppliers prioritized tools for optimizing logistics, such as route planning and delivery scheduling. Both parties agreed on the importance of integrated communication features, such as instant messaging or notifications, to reduce miscommunication. Conversely, they expressed a preference to avoid overly complex systems with redundant functionalities, as these could slow down operations or create confusion. Privacy and data security were also cited as non-negotiable elements, ensuring that proprietary information and sensitive business data remain protected. Overall, the expectation is for a collaborative, scalable, and efficient digital solution tailored to the unique demands of small-scale construction supply chains.

5.9. Factors Affecting Productivity

The productivity of small-scale construction supply chains is influenced by several key factors that both suppliers and engineers identified as critical in their responses. One of the primary factors is the availability and timely delivery of materials, as delays in receiving supplies directly impact project schedules and labor productivity. The accuracy of inventory management also plays a crucial role; improper stock levels, whether due to stockouts or excess inventory, can lead to wasted resources or project delays. Another significant factor is the efficiency of communication suppliers, engineers, and contractors, with breakdowns in communication often resulting in misunderstandings, delayed orders, or incorrect deliveries. Additionally, the lack of digital tools or automated systems to track inventory, orders, and deliveries contributes to inefficiencies and manual errors that hinder productivity. The ability to manage unexpected changes in material requirements, often arising from design alterations or unforeseen site conditions, also affects the overall efficiency of the supply chain. Finally, the skill & experience of personnel involved in the supply chain, from procurement to delivery, significantly impact decision-making, problem-solving capabilities, and the ability to adapt to changing conditions, further influencing overall productivity.

Conclusion

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In conclusion, the findings from the qualitative questionnaire survey, which involved open-ended questions directed to both suppliers and engineers in small-scale construction projects, provide valuable insights into the challenges and inefficiencies plaguing the traditional supply chain process. The responses clearly indicate that the current supply chain is fragmented and heavily reliant on manual processes, which creates a significant risk of delays and errors. Suppliers reported difficulties with inventory management, often relying on basic record-keeping systems such as spreadsheets or physical ledgers, which leads to frequent discrepancies in stock levels and challenges in meeting the material demands of construction projects. Engineers, on the other hand, face difficulties in ensuring the timely delivery of materials, often due to miscommunication, inaccurate forecasting, and the absence of real-time updates. Delays in material delivery disrupt the construction schedule, leading to idle time for labour and equipment, which results in higher costs and reduced productivity. The survey also highlighted the widespread lack of knowledge and adoption of digital tools within the small-scale construction sector. While some suppliers and engineers are aware of basic inventory management software, there is a clear gap in understanding and utilizing advanced technologies such as real-time tracking systems, Construction 4.0 tools like IoT sensors, and AI-driven analytics. This gap prevents stakeholders from optimizing their supply chain operations, limiting their ability to respond to material shortages, unexpected changes in requirements, and delivery delays effectively. Both suppliers and engineers expressed a strong interest in the implementation of Construction 4.0 technologies, with suggestions for a user-friendly, integrated digital platform that includes real-time tracking, automated alerts, demand forecasting, and improved communication tools. They emphasized that such systems should be simple, scalable, and secure, with the goal of enhancing transparency and coordination throughout the supply chain. Furthermore, the survey responses underscored the importance of better logistics management, efficient communication strategies, and proactive planning. Addressing issues such as traffic congestion, vehicle breakdowns, and limited transportation resources was seen as essential for improving timely material delivery. In addition, both groups acknowledged the need for a more robust approach to handling unexpected changes in material requirements, which often lead to rushed orders and disruptions in project timelines. Overall, the results of this survey emphasize the need for a comprehensive transformation of the small-scale construction supply chain. By adopting digital solutions, improving communication, and implementing better planning and forecasting practices, small-scale construction projects can overcome the existing inefficiencies and challenges, leading to improved productivity, reduced delays, and better project outcomes. The integration of Construction 4.0 technologies, in particular, holds the potential to revolutionize the way supply chains are managed in the sector, creating more resilient, efficient, and responsive operations.

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